REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 07/21/97	3. REPORT TYPE AND DATES COVERED Annual Report 07/96 – 07/97

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Development of low loss multipole RF filters	N00014-96-1-G017

6. AUTHOR(S)

Q.Y. Ma

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Columbia University Department of EE, 1312 Mudd New York, NY 10027	Annual 97

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Dr. Martin Nisenoff, Program officer, Code 6850.10 NRL (Naval Research Laboratory) 4555 Overlook Ave., SW Washington DC 20375-5326	

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Approved for public release	

13. ABSTRACT (Maximum 200 words)

In short summary, we have designed, fabricated, and tested three-pole filters of 15 MHz. We proved, for the first time, that a single layer low-end frequency RF filter can be made on a two-inch HTS wafer. The performance of the filter showed a close center frequency and a high quality factor. There are, however, large difference in bandwidth, insertion loss, and passband ripple between the design and the measurement. The possible reasons have been determined and modifications will be incorporated into the design for the next phase work.

DTIC QUALITY INSPECTED 4

14. SUBJECT TERMS			15. NUMBER OF PAGES
			16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Columbia University in the City of New York | *New York, N.Y. 10027*

DEPARTMENT OF ELECTRICAL ENGINEERING
Seeley W. Mudd Building

Tel: 212-854-5080
Fax: 212-854-1909
qyma@ee.columbia.edu
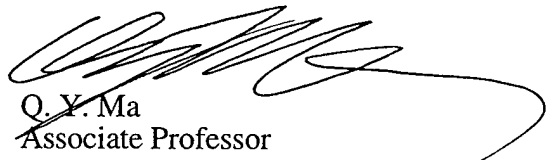
July 21, 1997

Dr. Martin Nisenoff
Program Officer
Code 6810.10
Naval Research Laboratory
4555 Overlook Ave., SW
Washington DC 20375-5326

Dear Dr. Nisenoff:

Enclosed please find the annual progress report on the project under the grant N00014-96-1-G017. This report will update you on the work we have done so far. We seek your advices and comments on the planned work for the next year.

A copy of this report will also be sent to Dr. Frank. Patten and Dr. Stuart Wolf. Thanks.

With best regards,

Q. Y. Ma
Associate Professor

Enclosure:
Annual report.

Annual Progress Report on the Project

Development of Low Loss Multipole RF Filters

Grant NO. N00014-96-1-G017

July 21,1997

Q. Y. Ma

Department of Electrical Engineering, Columbia University,
New York, NY 10027
Tel: 212-854-5080, Fax: 212-932-9421

Abstract

HTS three-pole bandpass filters of 15 MHz have been designed, fabricated, and tested. It was proved, for the first time, that a single layer low-end frequency RF filter can be made on a two-inch HTS wafer. The performance of the filter showed a close center frequency and a high quality factor. There are, however, large difference in bandwidth, insertion loss, and pass band ripple between the design and the measurement. The possible reasons have been determined and modifications will be incorporated into the future design.

1

A) Work Report

The original technical objectives for the first year include: 1) design a five-pole HTS filter, using interdigital capacitors and meander-line inductors, with a center frequency near 15 MHz and with unloaded Q-values of 10,000 or more; 2) fabricate filters described in 1) above by using either ion implantation or etching techniques; 3) measure the performance of the filters as a function of temperature and incident power; and 4) make several iterations of the design to optimize the performance of the filters.

1) HTS Wafer Materials

Three batches of YBCO films were purchased from Prof. Kinder's group in Germany. All wafers were deposited by co-evaporation. First batch consists of 5 double-side films (2000 Å) on 3 inch $LaAlO_3$ substrates. The films in this batch have very smooth surface but a low T_c of 80 - 84 K and J_c of 1.2×10^6 A/cm^2 at 77K.

The second batch consists of 12 single-sided YBCO films (2000 Å) on 2 inch substrates and third one with 5 single-sided YBCO films (3000 Å) of 3 inch in diameter. The films in both second and third batches have a Tc of 87 K and J_c above 2×10^6 A/cm^2 at 77K.

2) Five-pole Filter Work

We have made several different design layouts. After computer simulations one layout had been finally chosen which was based on interdigital capacitor structure. The design requires many pairs of fingers (500 pairs with 13 um width and spacing) to achieve the large capacitance necessary for the 15 MHz filter, and occupies a large area (about 3 cm x 4 cm for each pole). By adjusting the numbers of capacitor pairs, one can precisely control the resonance frequency. To test this filter design, we have made a mask of a one-pole filter. The prototype filter is 3 cm x 4 cm in size.

We have fabricated two one-pole filters using the first mask by chemical etching and by ion implantation. Testing of the filters at cryogenic temperature (below 77 K) was carried out by Dr. Jeff Pond at NRL. However, both devices did not show superconducting.

The big problem with the five-pole filter was to design the circuit on a 3 inch wafer. After several design attempts, it was still not feasible to fit the filter into a 3 inch wafer.

The PI had a meeting with the contract officer, Dr. Martin Nisenoff, on May 15, 1997. It was decided that we change the design from 5-pole filter with center frequency (f_0) of 15 MHz and a bandwidth of 10 % f_0 to 3-pole filter with the same center frequency but a much narrow BW of 0.1 % f_0.

3) Three-pole Filter Work

a. Design

This bandpass filter was transformed from a standard 3-pole Chebyshev lowpass filter with specifications shown as below.

Central Frequency f_0	15 MHz
Band width (BW)	15 kHz (0.1% f_0)
Quality factor	1000
Insertion Loss (S12)	< 0.3 dB
Return Loss (S11)	< -20 dB
Stop Band at 4 times BW	< -40 dB

Figure 1 shows the circuit of the three-pole filter with all the values of capacitors and inductors. The unit is pF for the capacitors and nH for the inductors. The circuit was simulated using the HP EESof, a microwave communication circuit simulation program, and the results were shown in Fig. 2. The specifications were listed above.

To implement such a circuit on HTS thin film, we chose corresponding microstrip line structure. The model for large inductor in EESof library requires a gold bridge to connect the center lead to the circuit outside the inductor which causes more loss. In order to reduce the loss, we used a meander line inductor as the coplanar structure. This design increased the total area slightly but minimized the loss associated with wire bonding. The final layout, as shown in figure 3, fits well on a two-inch wafer.

b. Fabrication and Testing

Two photo masks were made: one for the three-pole filter and the other for the testing of individual capacitors and inductors. The layout of the test structure was shown in figure 4. Several samples were fabricated on two-inch wafers using chemical etching. After fabrication, 50 nm silver and 150 nm gold metal layers were deposited and patterned

to form contact pads. Fig. 5 (A) shows a picture of the three-pole filter and Fig. 5 (B) shows the test structure.

Two filters, labeled as filter1 and filter2, were tested at Naval Research Laboratory at a standard microwave test bed. The temperature in the system could be adjusted from room temperature down to 10K. A gold/indium plate was used as grounding plane. All filters were tested at different temperature (13K, 30K and 50 K) and different input power levels. The results are summarized in Table I. After testing, condensation was found on filter2 during warm-up process which degraded the superconductor. Figure 6 shows the S-parameter response of filter1.

Filter	Tc (K)	f_0 (MHz)	BW (kHz)	I. L. (dB)	Pass Band Ripple (dB)
filter1	60-70	18.25	300	-20	10
filter2	50-60	17.7	60	-15.4	2
design	-	15	15	0.3	0.3

Table I. Test results of the filters

From Table I, it could be seen that the central frequency of the filter is off by about 20%, and the bandwidth is broaden. The quality factor (Q) of the filter was measured to be about 250, four times smaller than designed value. Insertion loss and pass band ripple are higher than expected. In addition, the filter samples are power sensitive. The power was set to -20 dBm for all measurements. Several interdigital capacitors and meander line inductors were also tested in order to get more precise model and improve the design.

c. Analysis and discussion

The test result is not so satisfactory as desired. However, as the first trial, this result gives us as much information for further modification. Several reasons for the differences between the filter performance and the design and improvement can be made in the following areas.

Center frequency

The central frequency is determined by the capacitor and inductor in each resonator. The 20 % shift in f_0 may be due to the difference in determination of the capacitance and inductance of the filter components.

The test result of the interdigital capacitor shows that the capacitance derivation is within 2 % as designed, which is very desirable. But large derivation was observed for meander line structures. To precisely control the inductance, we need to further improve the model and to test more inductors with different inductances.

Bandwidth and insertion loss

The characteristics of bandwidth, insertion loss and ripple are related to three resonators. We believe the large difference between designed and measured values are due mainly to the coupling capacitors between each resonator.

The coupling capacitor (about 0.2 pF) is several orders smaller than the resonance capacitor (200 pF). If we consider parasitic capacitance of the interconnect microstrip line and inaccuracy occurred in device fabrication, the derivation could be the same order as the capacitor itself. This leads to a wide pass band with a large insertion loss and pass band ripple as shown in figure 6. After we measured the capacitance of the individual capacitors and fit the values into the simulation program, the new simulation showed very similar results as the experimental data, as indicated in Fig.7.

This leads us the direction for improvement. In the next step, more small interdigital capacitors with interconnecting wires will be tested. Accordingly, the layout will be modified in order to absorb the parasitic capacitance.

Grounding

The third area for improvement is the grounding. In our experiments, the gold/indium plate used as the grounding plane was found to increase the loss by several times. Superconducting grounding plate should be used for the filter in the future.

Alternative design

In addition, we have also made a new approach in designing multipole filters. It is based on multilayer spiral resonator. The spiral inductor design requires a smaller area compared to the interdigital capacitor design. The challenge here is that the resonance frequency depends strongly on the properties of the substrates and processing of the double-sided films. We are working on a theoretical model for this structure which accurately accounts for the electrical properties of substrate. We are currently making the mask for fabrication of a resonator. We plan to design the three-pole filter using this approach after the resonator is tested.

4) Summary

In short summary, we have designed, fabricated, and tested three-pole filters of 15 MHz. We proved, for the first time, that a single layer low-end frequency RF filter can be made on a two-inch HTS wafer. The performance of the filter showed a close center frequency and a high quality factor. There are, however, large difference in bandwidth, insertion loss, and pass band ripple between the design and the measurement. The possible reasons have been determined and modifications will be incorporated into the design for the next phase.

B) Work in the Next Year

The work in the second will be to continue the three-pole filter project by several modifications:

1. Change the grounding plane to superconductor;
2. Test more meander line structure;
3. Test more small interdigital capacitor;
4. Modify the layout according to the result from 2 and 3;
5. Fabricate, test and deliver several filters.
6. Make several iterations of the design and fabrication to optimize the filter performance.

We expect to accomplish above tasks within the first half year. This includes two turn around cycles of design-fabrication-test.

Then we will move on to the design, fabrication, and testing of a multilayer RF resonator as well as three-pole HTS filters with center frequencies of 15 MHz and 5 MHz.
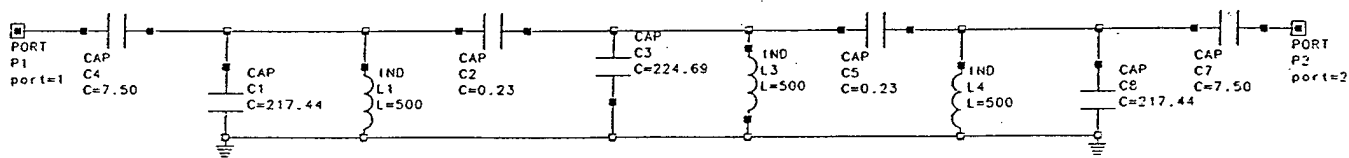
Fig.1 Lumped Element Circuit of the Band Pass Filter
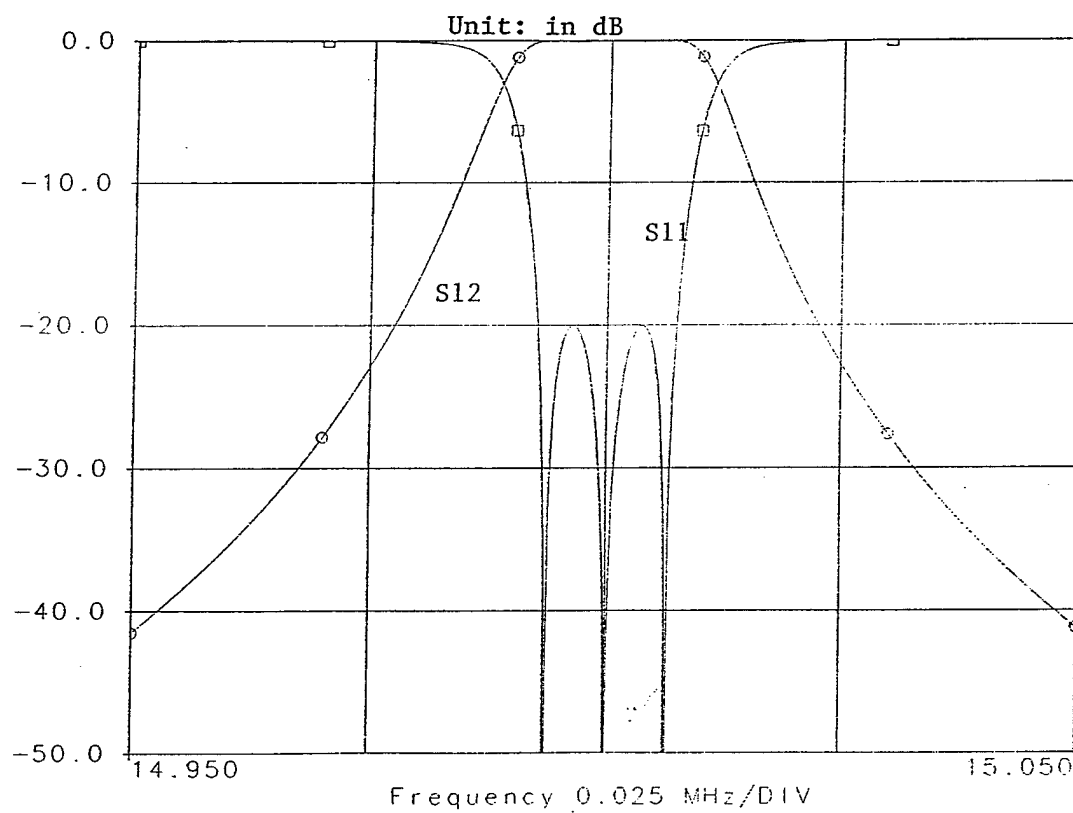

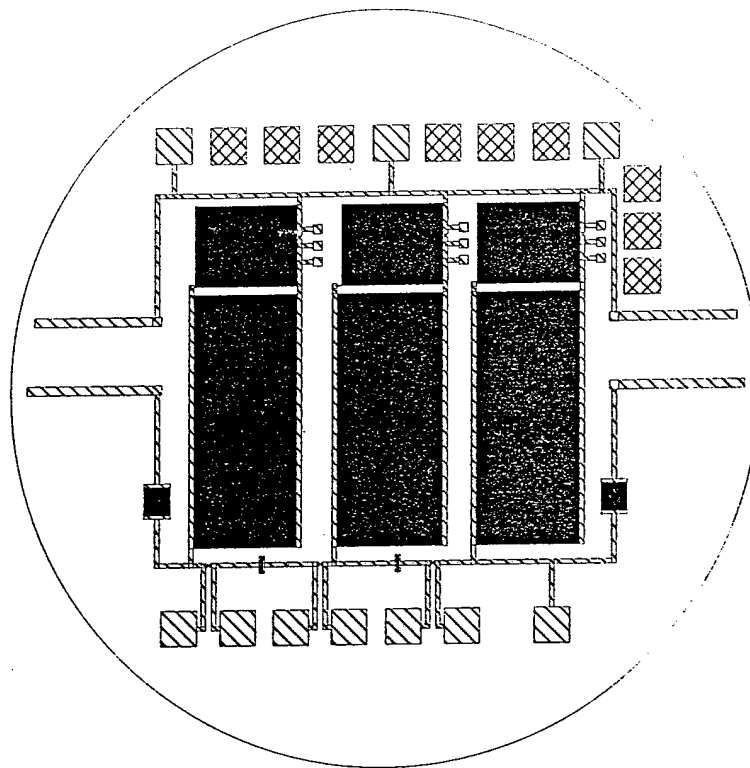Fig.2 Simulation Result of the Filter under HP EESof

Fig.3   Layout of Filter (the circle represents a 2-inch wafer)
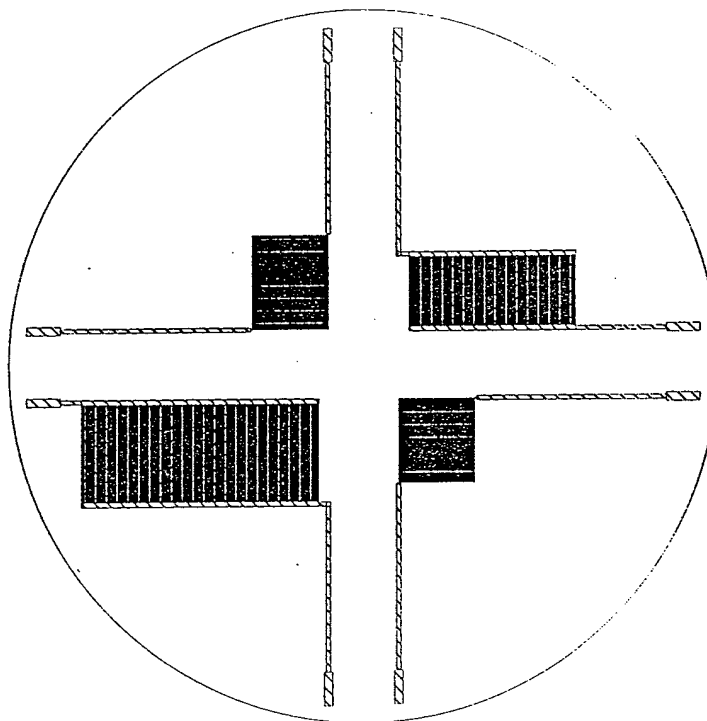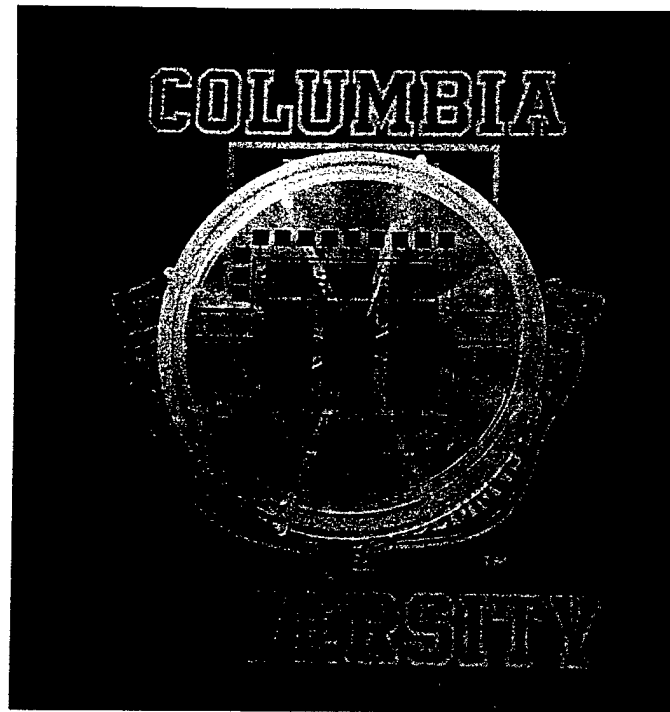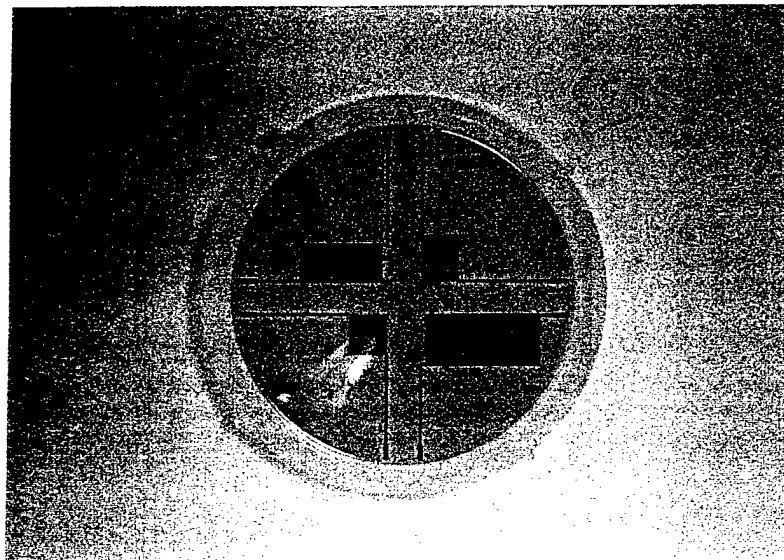
Fig.4   Layout of testing structure on a 2-inch wafer

(A)

(B)

Fig.5 Layout of (A) 3-pole filter, (B) Testing structure of capacitor and inductor
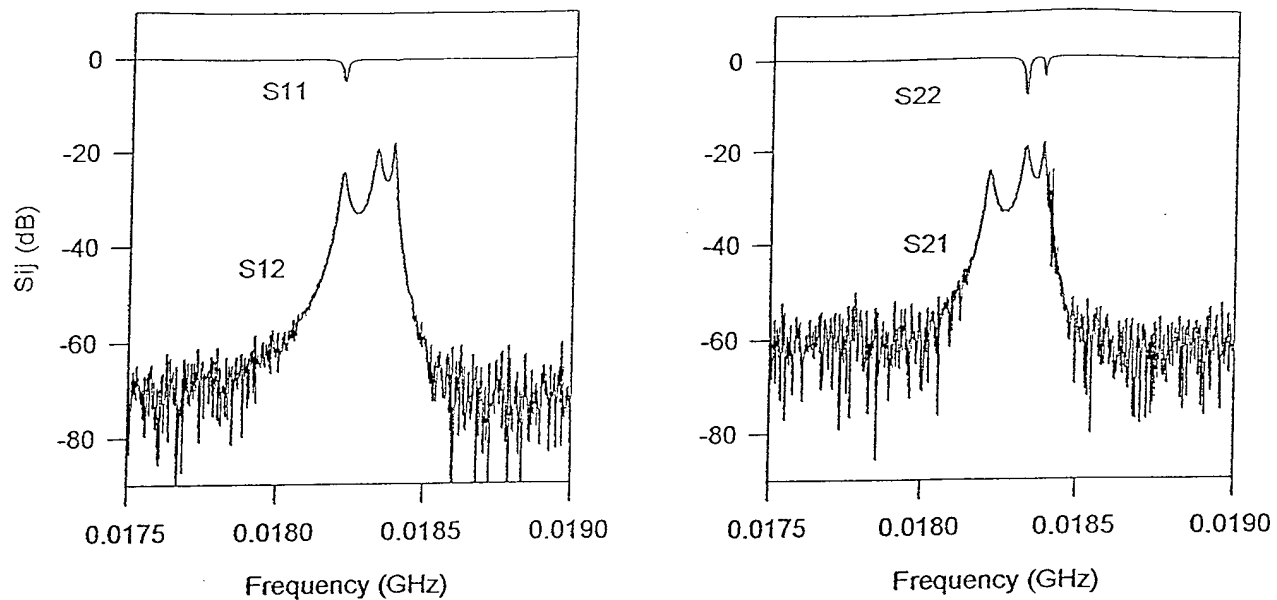
0

S11

-20

Sij (dB)

-40

S12

-60

-80

0.0175   0.0180   0.0185   0.0190

Frequency (GHz)

0

S22

-20

S21

-40

-60

-80

0.0175   0.0180   0.0185   0.0190

Frequency (GHz)

Fig.6 S-parameters of filter1 at 13K

S11   Unit: in dB   S12
0.5   -25.0

0.0   S11

                            S12
-0.5

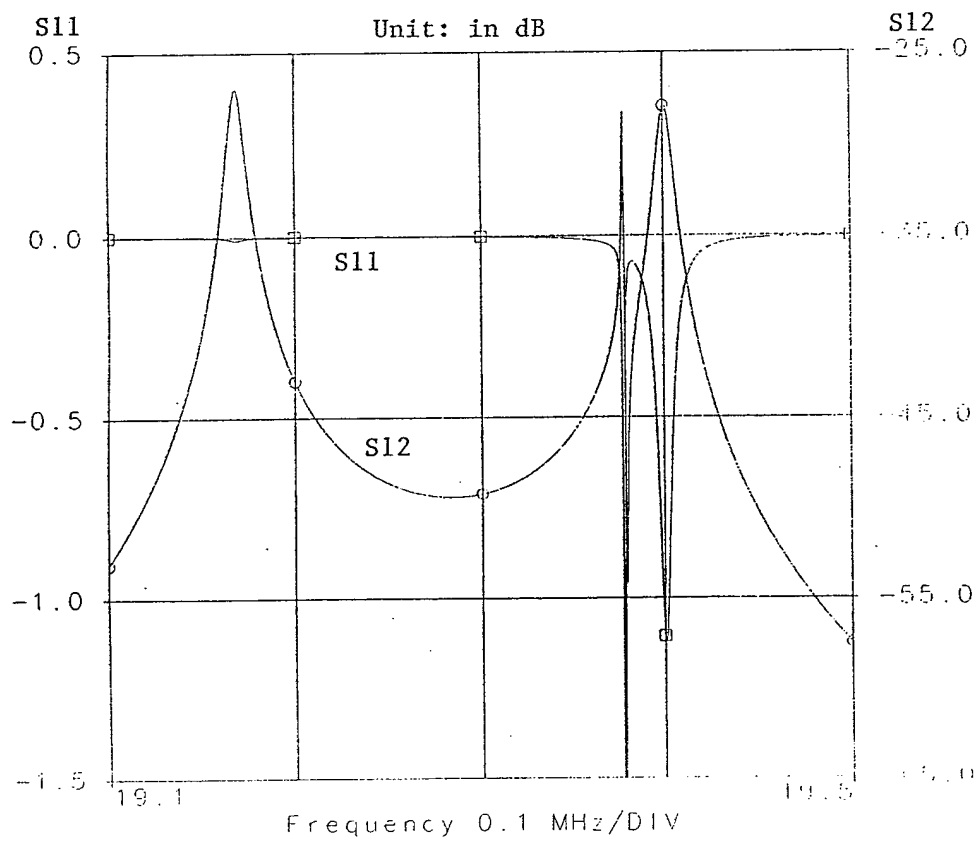-1.0   -55.0

-1.5   19.1

Frequency 0.1 MHz/DIV

Fig. 7 Simulation result after adjusting coupling capacitors